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MAN IN A WORLD OF INSECTS

DWIGHT M. DeLONG†

Professor of Entomology, The Ohio State University, Columbus

Numerous scientific scholars have attempted to define or name the present age of biological development in line with past evolutionary ages. The geologist has referred to it as the Cenozoic Era, "the age of man." Others have referred to it as the Psycozoic Era.

This is undoubtedly the result of the general belief that man is the dominant and superior type of animal on the surface of the earth and believes that he is capable of conquering or subduing every other form of life.

Of course we are extremely egotistic. Many of us believe that the world was created for us and that everything on the earth is intended in some way, directly or indirectly, for our use or benefit. But the truth is that man is only one of the recent products of organic evolution.

It is true that man has become the dominant type of vertebrate animal but he must constantly be aware of, and compete with, the dominant type of invertebrate, "the world of insects," which comprises four-fifths of all of the animals on the earth, some 800,000 species, and which man has never subdued. One author has referred to this era as the "age of insects," another to it as the "insect menace" and a recent film which is an excellent portrayal of this struggle is entitled "The Rival World."

When primitive man arrived on the earth as a product of evolution, he found the world already occupied and well populated with insects. This has been proven to us by the paleontologist and his undisputable evidence of fossil records.

The paleontologist tells us that insects are recorded in the late Paleozoic, which was some 200 million years ago, and at that time they were well developed, so that they must have appeared much earlier. There cannot be the faintest doubt that millions of years must have transpired in the evolution of the insect world as it existed in the upper Carboniferous period. This historic evidence leads us to believe that insects came into the world some 300 million years ago or more, became highly developed through rapid multiplication by means of quickly developing, short cycle generations, and by rapidly evolving through ages of time they have become highly adapted and perfectly fitted through mutation and selection to every natural condition on the earth, down to the present time.

The mammals in general and man in particular arrived in this insect world long after the insects had taken possession of practically every habitat on the earth. Primitive man arrived not more than a million years ago, some authorities say about one-half million. Modern man has been here not more than 50,000 years. He is not so adapted as the insect; he is a comparative newcomer. He spends his time and efforts converting the materials of the natural world into man made structures and plantings. Unlike the insect, he does not attempt to live in the natural world as he found it. This causes living conditions to be more complex and more difficult.

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The evolution of the insects was apparently not always successful for in the late Carboniferous period we find enormous cockroaches and dragonflies with a wing spread of more than two feet in some species. These apparently have long since been lost as failures in a competitive organic world but look at the successful mutants which have arisen from these ancestors. The selected, present day species of roaches are the German, American, Oriental, and others which inhabit our homes and kitchens, invade our restaurants, markets, and night-clubs and are carried everywhere in trucks, steamships, airplanes and other conveyors in all type of receptacles, whether they contain food, clothing or other types of materials.

In so far as historic records are available, man has in all ages since his arrival on the earth been tormented or destroyed by the ravages of insects upon him directly or upon his food and possessions. On the other hand, he has often turned to the insect as a source of nourishment to sustain life.

The Bible is often referred to as an excellent source of history of man through a limited period of his existence. Certain portions are probably more fact recording while others are largely philosophical. The authors who wrote the Bible point out the occurrence of many insects, ants, bees, locusts, lice, fleas, hornets, flies, and moths, for example. The terrific populations of migratory locusts (grasshoppers) are described which completely destroyed the crops and devastated the fields. This is quite similar to the devastations of the forage crops of our own plain states by migratory grasshoppers—the Rocky Mountain Locust—in the middle of the 19th century.

The ant and the bee are cited in the Bible as examples of industry and aggressiveness. They are carved on Egyptian monuments. Grasshoppers, and honey and manna as insect products, are listed as foods which were apparently largely responsible for the sustenance of the children of Israel while they were sojourning in the wilderness.

Honey was a marketable product several thousand years ago; it was used in sacrificial offerings and was attributed to have medicinal qualities by the ancient people.

The majority of insect species have no economic status and are seen only incidentally by man. They are considered as neutral. The remaining forms could be divided into two groups, the constructive and destructive. If man attempts to evaluate the role of his economic insect associates, he will need to place on the ledger both assets and liabilities, namely, those insects which assist him and those which destroy him.

We speak of many insects as being beneficial to man, and although we may be reluctant to admit it, we are actually dependent upon insects for much of our food supply, either directly or indirectly. In fact, the peoples of the world could not be fed today except for their assistance.

Insect Assets—The Constructive

Insects and pollination.—Biologists in general have agreed that one of the major benefits derived from insects is the production of crops which result from their services as pollinating agents. It would be difficult to estimate the value to man of pollinating insects, but the sum is enormous.

Research and study have demonstrated that at least 50 agricultural crops depend on flower visiting insects for pollination, or yield decidedly more abundant crops when bees are present. This list as reported by the U.S.D.A. Bureau of Entomology and Plant Quarantine includes most of the important fruits and vegetables, forage crops, legumes, and certain special crops. The real value to man is the production of seed and fruit.

Without insects to effect pollination, many species of plants will not set seed or produce fruit no matter how well they are cultivated, fertilized. and protected from diseases and pests.

Although the honey bee is the most important pollinating insect, it is but one of many species of bees necessary for the perpetuation of flowering plants. Various species of flies, beetles, and other insects also visit flowers and to some extent pollinate them. The Bombyllidae are particularly known for their pollinating habits.

The importance of the honey bee is especially noted because it and certain wild bees must obtain nectar and pollen in order to nourish both the young and adults. This is not the case with other pollinating insects.

Furthermore, agricultural development has seriously interferred with the balance in nature by demanding enormous acreages for cultivation. The nesting places of wild and native pollinating insects have thus been destroyed. As a result the burden of pollination has been increased to such an extent that wild bees are no longer adequate or dependable. Honey bees must be introduced seasonally in certain specific areas for pollination, and they have thus become the most numerous of the flower visiting insects. It is essential, nevertheless, to work to conserve our native pollinating insects since some species of native bees are more efficient, bee for bee, than honey bees and will work under more adverse conditions.

Insect products.—Certain insects are of benefit to man by their direct production of materials which serve as his food, or from which he can manufacture marketable products.

The honey bees produce some 250 million pounds of valuable and nutritious food each year in the form of honey. They also produce several million pounds of wax which is used in a great variety of industries, including both war and peace time products. Wax is used, for instance, in the sealing and coating of shells, for ignition apparatus, in the manufacture of cosmetics, in candles for religious purposes, in dental supplies, in pharmaceutical salves, on carbon paper, in confections, in printers' ink, in engravers wax and in the lubrication of dies for drawing sheet metal tubes and cylinders.

In the Orient a pure white wax is produced by scale insects of the genus *Ericerus,* and in the semiarid regions of Mexico and the south-western United States wax is produced by scale insects of the genus *Tachardiella.*

Other commercial products of lesser importance or monetary value are produced by other scale insects. Especially important are the lac insects which occur in many of the tropical and subtropical countries, such as Ceylon, Formosa, India, the East Indies, and the Philippine Islands. These insects encase their bodies with a secretion which encrusts the limbs and twigs of trees upon which they live with a resinous deposit one-fourth to one-half inch thick. This wax is melted, refined, and placed on the market as shellac and is used extensively in the manufacture of paints and varnishes.

Certain other scale insects are called cochineal insects and are common on cacti in Mexico. Their bodies are collected, dried, and used by the native Indians for the preparation of a crimson or vermilion dye. In the 19th century a cochineal manufacturing industry was established in the Canary Islands where it flourished until 1875.

Insects as food.—Indirectly, insects are of great importance to the food supply of man the world over as they supply the basic or initial food materials that are transformed into the bodies of food animals, especially birds and fishes, whose flesh later finds its way to our tables. These insects are as much a part of the food chain for fish and fowl as corn is a part of the food chain for bacon, ham, or beef we eat.

While the value and acceptability of the bodies of insects as food for man might be questioned, there are many instances where they have been or are being used. Our close neighbors, the people of Mexico utilize several types of insects as food. The larval stage of a large hesperid skipper which lives in the maguey or century plant may be purchased alive in the markets in lots of ten or twelve, tied in a small sack made from the thin membrane of the maguey plant, or they may be purchased in cans placed in groceries or food stores by commercial canning companies.

At one of the regular meetings of the Columbus Entomological Society in 1941 these larvae were served as refreshments and some seventy-four of seventy-five persons partook of them upon this occasion.

Other insects used as human foods in Mexico are the eggs of certain aquatic Hemiptera, particularly Corixidae and Notonectidae, which are utilized for the production of an edible meal known as "ahutle." In towns near Lake Texcoco dried cakes containing these insects may be purchased in the markets.

Certain California Indians obtain in quantity from Mono Lake and other highly alkaline and saline lakes a brine fly, *Ephydra hians*, in the pupal stage, which is dried and furnishes a highly nutritious but scarcely appetizing food known as "Koochabe."

In the old world, grasshoppers have been eaten for centuries by man, native tribes commonly roasting them.

In the Belgian Congo, dried termites are sold in baskets at the native markets and termite queens are roasted or fried in fat. Termites are also eaten in the Oriental tropics.

Certain of the larvae of various large beetles are also roasted, fried, or boiled by the natives of several of the tropical countries. The Laos Indians of Siam feast upon both adults and larvae of one of the dung beetles.

Of the many specific types of insects which have been utilized as food, one of the most curious is the giant water bug, *Lethocerus*, which, being large in size, is steamed and then picked like a lobster.

Silk production.—Fiber for cloth is also furnished by the insect, providing you are financially able to purchase the cloth that is made. The silk worm has for many years been considered the second most commercially important beneficial member of the insect world. From modified salivary glands it has furnished the raw materials for large industries in both Asia and Europe, where caterpillars are reared and raw silk is produced. This has been an especially important industry of the Orient.

The chinese silkworm, *Bombyx mori*, is a native of Asia and has been reared in quantity in captivity for so many years that it is at present impossible for it to exist without human care. This rearing involves extensive hand labor. Silk is therefore a costly fiber and the industry is valued at millions of dollars. However, it is seriously threatened for its existence at present by the manufacture of synthetic fibers which are rapidly and largely replacing silk and by the growing trend toward the formation of democracies in the Orient, under which conditions the high cost of labor will be prohibitive.

Insects in medicine and surgery.—Man has recognized the medical value of insects and for some time has used their products as therapeutic agents. Cantharidin has been produced from the bodies of blister beetles and is used in the treatment of certain conditions of the urogenital system. The importance of this drug was probably not fully realized until the second World War when shipments of insects for its manufacture could not be secured from Europe. The pharmacists then became disturbed when they learned that different species of beetles contained different percentages of cantharidin and that the species in the United States yield very small percentages. As a result cantharidin has not and apparently cannot be produced on a commercial scale from native blister beetles.

Insects as healing agents.—While considering the drug industry, we might glance briefly at the use of blowfly larvae to render aseptic and hasten the healing of surgical wounds caused by osteomyelites. In a field dressing station in France a young surgeon during World War I observed severe shrapnel wounds containing infestations of fly maggots and noted the subsequent rapid recovery of the soldiers so infested. After returning to the United States he was responsible for the experimental treating of wounds of human patients with fly larvae of *Lucilia serricata* and *Phormia regina* reared under aseptic conditions. Through this treatment a therapeutic agent, allantoin, has now been developed and fly maggots are no longer being used. At present allantoin is being used in the treatment of osteomyelitis and other deep-seated wounds in which there is decaying tissue. The fact remains that it was through the use of fly maggots and a study of their physiologic action that a modern medical treatment was developed for a condition which was previously very difficult to cure.

Insect parasites and predators.—Although taken for granted by most biologists, some of the most valuable insects are those which live upon or within other insects, particularly noxious plant feeding species, and thus destroy them. We usually classify these as parasites and predators. Both types and quite important although the parasites are much more complex in their biology and adaptations.

Predation is a common mode of sustenance of many types of animals, including man. The powerful asilid fly thrusting its swordlike beak into a large bee reresembles the final thrust of the glistening sword of the colorful matador into the heart of a tired and floundering bull.

The development of predation in insects is hard to trace but we know that it existed in certain forms such as the dragon flies which were major types of insects in the late Carboniferous and early Permian periods.

The habit of predation is found generally throughout the insect orders. In many species and groups, however, predation may not be beneficial to man. This is especially true in the case of the large group of aquatic predatory insects.

In case the predatory habit might be beneficial, such as the aphid feeding habit of the tree crickets, the benefit is often offset by an injurious habit such as egg laying in the twigs or stems which causes untold injury to the plant or crop.

There are many groups in which predation brings enormous value to man. This is particularly true of those insects which feed upon colonies of aphids or attack caterpillars upon the ground. Most of these have insatiable appetites and are, therefore, important factors in the control of the insects upon which they prey. Certain accurate data will further amplify this statement.

A labybird beetle, *Coccinella californica*, according to Clausen requires 475 aphids at the rate of 25 a day for development and after transforming into an adult beetle eats 34 per day during its remaining life. Perhaps the greediest coccinellid species recorded is *Chilocoris similis*, which Nakayama has found consumes on an average 1563 aphids per individual during its lifetime.

In the case of the aphis lion, *Chrysopa californica*, a larva may consume 141 aphids during its larval development.

The Syrphid Fly larvae have equally voracious appetites. Two species reported by Curran, *Allograpta obliqua* and *Syrphus americanus*, consumed 265 and 474 aphids, respectively, during their larval development.

The ground beetles, one of the largest families of Coleoptera often attack larger insects. We should emphasize their importance by stressing the fact that here is a predacious group which covers the surface of the earth, continuously patrolling it and devouring untold numbers of insects, particularly caterpillars whose life cycle is such that they must drop to the ground as full grown larvae and penetrate its surface twice, once to pupate and again to emerge. This offers the opportunity to our carabid patrolmen to see that few pass or repass without being apprehended. Considering the large numbers of prey that are destroyed by a single individual during the course of its life, we are forced to admit that predatory insects play a primary role in checking the increase of destructive forms and are of great value to man.

Insect parasites.—Insect parasitism is extremely diverse and it may verge on predatism, scavengerism, and commensalism in some instances. In addition to this there is a wide range of parasitic behavior among the truly parasitic species. This is probably due to the fact that parasitism has arisen in various groups of insects independently, but certain parallel developments have occurred among these different types.

One group of parasitic insects is known as ectoparasites and these are predominantly blood sucking species such as mosquitoes, black flies, horseflies, blood sucking lice, bedbugs, other Hemiptera, etc., which attack vertebrate animals. With few exceptions these are not beneficial to man.

The entomophagous parasites are usually forms that feed inside of the bodies of their insect hosts and either destroy them or render them sterile so that they are not able to reproduce. These parasites are known to occur in several orders. One insect order alone, the Stepsiptera, is composed entirely of parasitic species. These develop internally as parasites of bees, wasps, and certain Homoptera.

By far the greatest number of parasites are Hymenoptera and probably half or more of the known species of this group are parasitic on other insects.

Certain minute forms like *Trichogramma* will parasitize insect eggs, and an individual parasite can develop to maturity within the egg of the host. Others such as the brachonids or ichneumons may parasitize the larvae. The larval parasites are frequently quite specific and a high percentage of the host species may be destroyed.

As an example of this type of parasitic control the soil under a tree or plant may be so completely covered by the empty cocoons of brachonid parasites that the surface appears white.

An experience encountered a few summers ago is further evidence of the percentage of parasitism. An attempt was made to secure a number of normal sphinx moth larvae on catalpa. Several hundred individuals were collected from a small area of concentrated plantings and after examining some 300 specimens not a single larva was found free from parasites.

These parasites are of enormous value to man in the continuous combating of almost every important economic insect pest and many others would probably become important pests if it were not for the parasites which constantly hold them in check.

One of the most interesting and remarkable examples of the importance of insects as natural enemies is the practical and almost exclusive use of insect parasites and predators in the control program of orchard insects in the fruit area at Kentville, Nova Scotia, Canada.

In some cases where we cannot estimate the value of natural enemies we might find that without beneficial forms the other side of the ledger, the economic losses might be greatly increased.

Insects as scavengers.—The insect scavengers are those which feed upon decomposing plants or animals, or on dung. Such insects assist in converting these complex organic materials to simpler chemicals which are returned to the soil where they are available to plants to again produce new organisms.

Carrion feeding insects such as blowflies, carrion beetles, rove beetles, skin beetles and others are of value in removing or often burying carrion. Dung beetles of several families and dung flies hasten the decomposition of dung. Insects such as termites, carpenter ants, wood boring beetles and other wood feeders are important agents in hastening the conversion of fallen trees, logs and stumps to soil. The galleries of these insects serve as avenues of entrance for fungi and other organisms of decomposition which hasten the breakdown of the wood.

We have observed the organic cycle in nature since our first recollections and as a result we have usually accepted this condition without further thought. The value of such scavengers can be best emphasized by asking how long we would be able to survive in a world where dead bodies of plants and animals were not broken down and returned to soil and where the earth's surface would as a result in time become covered to a depth of several feet with such organic waste. These insect scavengers are indeed essential to maintaining a balance in nature.

Importance of soil insects.—Many types of insects spend part or all of their lives in the soil. The soil often provides the insect its home where many life activities and processes are carried on. Many forage above the surface carrying organic materials below, where new tunnels or burrows are continuously made. The soil is thus aerated and continuously enriched by their excretions and the decomposition of their dead bodies. In this manner soil insects improve the physical properties of the soil and add to its organic content.

We should hasten to add that soil insects vary greatly in their feeding habits and some which are root feeding forms in the larval stage, such as white grubs and wireworms, are quite injurious and are of much more harm than benefit to man.

There is no question however that many soil inhabiting forms are beneficial and are of value to man.

Insects destroy noxious plants.—A survey of insect feeding habits has established the fact that a large proportion of insects feed on plants but only a small number of these are considered pests. Many of the others may be beneficial by destroying cacti, noxious weeds or undesirable deciduous plants. It often happens that when a plant is introduced into a new geographic area it thrives to such an extent that it becomes a pest. In some cases plant feeding insects have been introduced to bring this plant under control. The prickly pear cacti (*Opuntia* spp.) were at one time introduced into Australia, and by 1925 they had spread over some 25 million acres to form a dense, impenetrable growth. In 1925 a moth, *Cactoblastis cactorum* (Berg.), the larvae of which burrow in the cactus plants, was introduced into Australia from Argentina. As a result of the continuous feeding of these moth larvae the dense cactus growth is now reduced to about 1 percent of the area it occupied in 1925.

It should be noted that weed feeding insects are not always beneficial. In some cases the weeds may serve only as an early seasonal food plant for the production of large populations which will later in the season attack and injure cultivated plants or crops. This type of problem is seen in the case of the sugar beet leafhopper. On the other hand, the insect may change its food preference from a wild to a cultivated host. The Colorado potato beetle, for example, originally fed on wild species of *Solanum* and later changed to potato.

The aesthetic value of insects.—The beauty of insects, their brillant colors and color patterns have been utilized by artists, jewelers, and designers. Some of the butterflies, moths, and beetles have provided basic patterns in many types of art. They have probably been utilized more because of their larger size and thus these patterns are more often seen. Some of the smaller insects are just as brilliantly colored and are often observed. For instance a brilliantly colored tropical leafhopper, *Agrosoma pulchella* (Guerin), has a black, white and red pattern of bars or stripes which is frequently used in Mexican and Central American art. The ecology and abundance of this insect account for its use in color designs there. It occurs in the lower tropical areas on shrubbery and is commonly found along streams where the natives launder their clothing. When their white garments are spread upon the shrubbery to dry, these brilliantly colored leafhoppers hop upon the clothing and the conspicuous color is emphasized by the white background.

Insects are also used in making jewelry, either by the use of all or part of actual specimens, or by their use in designs. Necklaces, necktie pins, bracelets, and scatter pins are often made in the design of an insect. In some tropical countries the natives make necklaces of "ground pearls," the wax cysts of female scale insects of the genus *Margarodes*. The wings of morpho butterflies, brilliant bluish butterflies occurring in South America, are often mounted under glass and made into trays, pictures and certain types of jewelry. Showy insects mounted in plastic or under glass are sometimes made into paperweights, book-ends, and similar types of useful articles.

During the last few years the Department of Fine Arts at The Ohio State University has annually requested certain of these insects with brilliant coloring or exquisite patterns for use in its laboratories, so that students specializing in fine arts might become acquainted with this source of material and might have an opportunity to use some of these designs in their period of training.

The recreational value of insects.—Insects are fascinating animals when one takes the time to observe them or begins to study them carefully. Therefore, many persons find in the study of insects a stimulating hobby and a means of recreation, just as intriguing and beneficial as any other type of nature study.

The interest in insect study leads to collecting and field study and to observations of habits and interrelations of insects with insects, insects with plants and with other biologic forms. The collecting, hiking, field activity and mountain climbing serve as an excellent form of recreation.

In order to improve his skill and to obtain recreation a man will push a golf ball over miles of fairway as often as he has the opportunity. When he returns from his hours of recreation, he has a score card, some sore muscles, and often a headache. If the same time were taken for insect collecting, equally important skills and techniques are developed; similar physical exercise is obtained, and in place of the score card an interesting catch of specimens is available for further study and recreation. It is true that the collector often has a headache too, but usually because of the interesting or intriguing specimens that escaped from his collecting net.

The scientific and educational values of such collections are also very important phases of the use of insects as a hobby. Some of the finest collections of certain groups of insects that we have in the world today have been formed in this way and often handed down for several generations. Several of these have been developed in the United States. In spite of this fact, the United States has fallen far behind the European and Asiatic countries in the practice of collecting insects as a hobby. This practice is found especially in Japan and certain of the central European countries. Scientists from these countries who have visited the United States during the past few years have expressed their astonishment at the lack of interest by the American people and the comparatively few amateur entomologists found in our country.

Insect Liabilities—The Destructive

The liability side of the ledger is illustrated by the destructive insects which destroy our crops, eat through the wood of our homes and buildings, make sneak attacks upon our supplies of food in pantries and larders, and pierce the skin of our bodies, thereby injecting deadly disease organisms into our blood.

Insects eat, steal, or destroy one-third of everything which man grows and stores for the future. This includes fields of corn and wheat, orchards of fruits, fields of potatoes, peas and tomatoes, vineyards, citrus groves, and all other types of crops.

Certain wood boring insects attack and fell our forest trees. Others inject disease producing organisms into certain trees causing Dutch Elm disease, Phloem Necrosis or Oak Wilt which take their toll of our forest and shade trees. When not destroyed in this manner, the lumber which is made into buildings is continuously attacked and destroyed by termites and powder post beetles.

Borne diseases of man.—The most direct and fatal attacks are by those insects which feed upon the blood of man. The world health authorities, working through the United Nations and gaining knowledge and statistics from all the nations of the world, are authority for the statement that insects are the cause of one-half of all human deaths, sickness, disease, and deformity.

The anopholine mosquitoes alone are responsible for injecting into man's blood stream the protozoans which cause malaria—a scourge which infests one-sixth of the human race and kills somewhere in the world a man or woman every ten seconds. In like manner the aedes mosquitoes are vectors of organisms causing yellow fever, a much more deadly human disease although not as widely distributed throughout the world.

The *Simulium* or black flies which occur in certain tropical areas around the world, inject into man's blood the microfilaria roundworms causing blindness (onchocerciasis) in man. Large segments of the native populations are often totally blind.

The tsetse fly is one of the most deadly of the blood sucking flies, causing sleeping sickness in man, which is usually fatal. Several million square miles of Africa have been so completely dominated by this insect that man has not been able to inhabit this area. The wild game animals serve as reservoirs for the trypanosomes which are carried to man by these flies.

Reasons for an Insect World

What is the character of these rivals which humanity must surely hold in check if it is going to be successful as a species? There are probably certain reasons which could be cited to explain why the insect type has become so highly evolved, adapted, selected, and so dominant and successful on the surface of the earth. To name a few of these briefly we could mention:

1. The body is enclosed within an exoskeleton which is composed of chitin. Its essential chemical elements, carbon, hydrogen, and nitrogen are easily and abundantly available from green plants in the form of nitrogenous sugars. A body covering of this type limits the insects to small size but affords great strength due to direct muscle attachments. It also favors diversified mutation and all types and extremes of protection through form, color, and thickness of the armor. This skeleton is always properly developed, in as far as diet is concerned, in spite of the fact that usually no parent is present to select the diet and feed the young. In contrast the human infant must be carefully nourished during his early life in order to obtain a proper skeletal structure and a healthy body.

2. Insects are the only winged invertebrates and this fact, combined with other survival characteristics, has given the insects dominance of the earth with which even other winged forms like the birds cannot compete. With wings insects can quickly abandon habitats when they become unsuitable. Aquatic insects have winged stages in their life cycles which solve the problem of desiccation, or in many instances they can develop wings in time to avoid death which might be imminent in many habitats. Fish and other aquatic forms usually perish under similar adverse circumstances.

3. The temperature of an insect's body usually follows closely the external temperature to which it is exposed. In order to adjust for seasonal changes the composition of the protoplasm is such that it can function as a hydrophyllic colloid, to the extent that it can absorb and bind the free water of the body. Thus by a short period of conditioning, insects in every life stage, depending upon the species, can be subjected to freezing and subfreezing temperatures and a certain percentage can survive long periods of low temperature. This adaptation to a condition of hibernation is one of the most important survival factors in the world of insects. This is the means by which most insects are fitted into a natural world and thus solve the problems of changing seasons. During the winter their bodies are quiescent and the metabolic rate is extremely low. When food is not available, they need no feed in order to survive.

Man on the other hand, who maintains a constant body temperature, must have fuel in order to retain a normal temperature during periods of low climatic temperature, as well as warm clothing to protect his body and a good supply of food to maintain a normal high metabolic rate and a continuous supply of internal heat and energy.

4. Metamorphosis in insects is a condition which is allied in a way to the previous consideration. Different biologic stages of activity and inactivity are often selective adaptations to seasonal conditions or feeding habits. The common cattle pest, the horn fly, is a good example of this. The only place that the larvae are able to complete their growth is in fresh cattle droppings. In hot, dry, summer weather these droppings soon desiccate. If and when they do, the maggots die. The selection factor here has produced a short maggot or growing stage of from two to four days.

Or take the case of a specialized plant feeding larva which attains great size during its short larval period. As a young apprentice of entomological research working with the United States Department of Agriculture in the tobacco growing sections of Tennessee in 1915, I was assigned the task of finding how much leaf tissue a tobacco horn-worm larva would consume between the time it hatched from the egg and the time it became a quiescent pupa. From the data I obtained and from the studies of subsequent workers, we can conservatively say that a single larva (tobacco worm) consumes in 28 days of larval growth food weighing approximately 50,000 times its birth weight, and the larva increases in size during this period approximately 12,000 times its birth weight.

Or look at the case of a silk worm larva which consumes its weight in food each day.

5. To these characteristics should be added the factor in insects of great biotic potential—the power of the insect to reproduce rapidly and establish enormous populations. This potential factor has been stressed by the theoretical estimates of many of our honest and reputable entomologists who estimate, for instance, that under optimum conditions a single cabbage aphis together with its accumulating descendents could, if enough cabbage were available, produce in a single growing season enough aphids, weighing one milligram each, to form a mass weighing 822 million tons or 5 times the weight of the total human population of the world. While this does not occur, the potential danger is always present in man's world of insects; and here or there, from time to time, where environmental resistance is restrained, the chinch bug, the Japanese beetle, the Mediterranean fruit fly, or some other specific form, will produce populations which get out of hand in spite of man's knowledge and continued efforts to subdue them.

Consider the potential of a common rainbarrel which has been observed to produce in excess of 100,000 mosquitoes in a single season. Regarding this potential, we should bear in mind that an average of only 1 per cent of the previous season's populations survives the period of wintering.

Certain insects, such as the digger wasps, in the absence of food preservation by low temperatures, habitually paralyze their prey by stinging them and then depositing their eggs upon these victims which are used to provision their galleries or burrows. In case these paralyzed insects should die the venom acts as a preservative and they will not decompose for periods of several weeks or even months.

The insect heart is a very unimportant structure in connection with respiration or oxidation. So heart disease, the great killer of humans, could not even occur in an insect. In like manner, insects have no lungs, no liver, and no kidneys. The respiratory system composed of a complex network of tracheal tubes is adapted to all types of aquatic life and is tolerant of both air and vacuum pressure, high altitude flight, and is more tolerant to radiation than vertebrate animals.

Also, consider the fact that in insects the infants, when born, usually take care of themselves; there is seldom parental care. Add to this the fact that there is no old age in insects. When their work is finished, they die. There is no retirement, no social security, no old age pensions, and never a feeble grandparent. All of these problems have solutions in a world of insects as a part of their adaptation.

Adaptations

Not only did man find these populations of insects in the world, but he also found extreme adaptations of these species by millions of years of survival selection. The extent to which insects will become adapted is amazing, and often shocking, at least when you use your imagination as to what might happen in the future. These adaptations occur in morphology, all phases of the biological cycle, habits, and physiology. May I point out a few examples of these adaptations?

The legs of insects are adapted in various groups for running, swimming, digging, grasping, and holding prey or in the case of blood sucking lice, of grasping and holding onto the hairs of mammals.

In the case of surface swimming gyrinid beetles, their eyes are divided so that one portion of the eye is above the surface of the water and the other is below.

In many insects which have hypermetamorphosis, the larva when first hatching from the egg may have well-developed legs and be able to seek out an egg mass upon which to feed; but when moulting to a second instar the legs become quite small and inadequate for locomotion. This condition is also seen in the scale insects which have an active first instar crawler stage and then become sessile and lose their legs in the second and succeeding instars.

Many interesting adaptations are seen in egg production. In some insect parasites we have a condition which is known as polyembryony. The female lays a single egg which eventually produces many individuals. Or take for instance the cannibalistic aphis lion where the survival factor is apparently accomplished by the eggs being layed on stalks and thus brothers and sisters are protected from the first of the brood to hatch.

In similar manner the giant water bug, females of the genus *Abedus*, glue the eggs to the back of the male where they remain until hatching.

Certain insects are adapted to extremes of climate. The Grylloblattids prefer temperatures of zero centigrade and apparently are unable to live at temperatures which are more than a few degrees from this point. They normally occur at the edge of melting glaciers. On the other extreme, certain insects live in hot springs with temperatures of 120° to 124° F.

There are many diversified adaptations in feeding habits and physiology among insects. The clothes moth larvae feed upon animal fiber (carotin) only, and never have available water as such. The water needed by the body is obtained through metabolic processes and the water released in the body from this source is conserved by the process of excretion and the production of dry fecal pellets. Stored gain insects conserve water in a similar way.

Gall insects, belonging to several orders, demonstrate another interesting phase of nutrition and interrelationship. In this case the insect produces a stimulus which is so specific that each individual of a gallmaking species will cause the plant to produce the same type of abnormal growth, inside of which the immature insect feeds, grows, and developes to maturity. Conversely, every different species of gall maker on the same plant will stimulate the plant to produce its own specific and uniform type of abnormal growth.

One of the most amazing adaptations is found in the ephydrid flies which live in saline, alkaline, or other solutions of extreme degree or variation. Certain of these occur in ocean water, in the Great Salt Lake, in the Bohemian salt mines, in pools of crude oil in California, and upon occasion some have been found living in cadavers in The Ohio State University Medical School which were preserved in strong solutions of formaldehyde.

An interesting survival factor is also displayed in the sexton beetles belonging to the Silphidae. These live in the bodies of exposed dead animals. The eggs are laid and the larvae develop in these carcasses, but the larvae must have soft, moist tissues to complete their growth. In hot dry weather these carcasses will desiccate rapidly. The species is thus preserved by the adults which dig the soil from under the carcass and gradually but rapidly bury it.

To the best of our knowledge the caddice fly larvae were the first organisms to demonstrate the use of nets to capture aquatic microorganisms. The dragonfly naiads, by the intake and repulsion of water to bathe the gills in the rectal cavity, gave us the first example of jet propulsion; and the paper wasps of the hornet group were the first to make paper by means of using wood pulp.

Natural Balance

It is impossible to predict what role the insects might have played in the world without the advent of man. There is no question that they had existed for millions of years and had become well adapted. Our observations, however, of areas of the world uninhabited by man have proved that natural conditions are usually well balanced until man's arrival. The number of insects and their interrelationships, parasites, predators, etc., the diversity of plants, and many other factors keep populations well balanced.

When man arrives he cuts down forests, cultivates fields containing many kinds of wild plants, and changes the fields to extensive acres of one kind of plant or crop. This breaks the balance and produces extensive populations of what we term economic insects.

The chinch bug is a good example. The corn belt was originally a grass land with an Andropogon Climax vegetation. This was the native food plant of the chinch bug which sucked the juices of the grass and hibernated in the adult stage in the clumps of dead grass at the base. Man decided he could raise the finest corn and wheat here. He plows out the Andropogon and plants two crops which he fertilizes and cultivates, causing them to grow rapidly, to be succulent and highly attractive to insects, and these two crops fit perfectly into the two seasonal generations of the chinch bug, spring on wheat, summer on corn; and then he wonders why these enormous populations destroy his crops.

In like manner man changes the course of streams, impounds water, constructs artificial barriers, and in general changes natural conditions, and in doing so he destroys the original balance.

The Struggle for Dominance

When we view man as a competitor in the insect world, attempting to subdue his invertebrate rivals, we must face up to certain facts and considerations.

The insect is an animal without intelligence, or at least the ability to think, which has come to its present position of dominance in the world by mutation, selection, and adaptation. As pointed out, it is highly adapted to most conditions in the world.

If there is any doubt concerning its ability to overcome anything adverse which is devised for its destruction, we have only to look upon the chemical developments and history of the past two decades. Man has devised the most deadly chemicals he could find in the chlorinated hydrocarbons and organic phosphates which at first seemed to deplete completely populations of houseflies, roaches, body lice, and most agricultural insects for months at a time. In five to ten years time these chemicals have proven absolutely ineffective on the descendants of these same insects.

When D.D.T. was first used, a prominent biologist stated that the house fly problem was forever solved. In five years from that date, we were rearing them in our laboratories in screen cages which were white with coatings of D.D.T. painted on the wire screen. Where does man hope to go in his fight with selective adaptation or tolerance of this type?

Man, on the other hand, is an intelligent animal with the ability to think and his choice of adaptation has been in this direction. In man we visualize another type of biologic experiment in the world. We see the development of an entirely different type of animal body with a different type of appendage, the hands, which he uses to make tools with which to made gadgets and devices for obtaining the materials and directing the forces of the earth, thus converting or changing the natural world around him. At the moment his greatest efforts seem to be in the direction of producing mechanisms of all kinds, including missiles, bombs, and devices for the exploration of outer space.

His intelligence drives him to an expanding horizon of activity so that he vigorously competes with other men and other races in order to control greater resources and materials in the world and command greater areas of influence. This leads to cold and other wars, and the destruction of man and his valuable possessions and international relationships.

Could it be possible that man has not been here long enough to be properly established since only about a half million years have elapsed from *Pithecanthropus* to present day man, and modern man has been here a comparatively short time?

At the present moment in world affairs a sudden misunderstanding or misstep, especially with the world's present stockpile of bombs, might eliminate man from large areas of the world in a single stroke. The insect populations under similar conditions would have a much greater chance of survival.

If this does not happen, where will man be in the next million years, attempting to live in a world full of established insects? The laws of evolution should work to improve the human race, but will this happen or can it happen in the world as we know it?

In order to meditate upon this thought it is necessary to recall that man is dual in nature. He must conform to his animal nature in order to meet and supply his physical requirements, but he wishes at the same time to be a spiritual creature in order to survive the physical world. He thus becomes involved in religious theories and doctrines, and he becomes confused and perplexed by biological laws, theories, and concepts. How far will religious prejudice, archaic concepts, and ecclesiastical dictatorship deter man from a sane pattern or philosophy of biological existence? Can intelligence direct the religious to augment the biological? If so, when may we expect it?

The biologist in his rational moments studies the laws of genetics as they apply to insects. He experiments with these in order to obtain and study certain gene combinations and marvels at what has happened in their evolution and adaptation. He applies the principles he discovers for the improvement of farm crops and farm and domestic animals, but he has not applied these basic biologic laws when he considers the human species and the possible and certain improvement of the peoples of the world. In the present world, he dares not.

Man then has not and cannot compete with the insect upon the same basis. It is a case of man's intelligence against biological adaptation, and repeatedly intelligence has lost skirmish after skirmish.

We could reflect in geological terms to the fact that nothing in the whole range of biological and palenotological study shows anything to equal the insect in its persistence and its potential compliment of characteristics, which would seem to assure its continued progress even if the experiment in the world of the human species would prove eventually to be unsuccessful.

We are reasonably certain from the past and present that the insect will persist and probably increase its position of dominance in the world. Can we predict the same for man? Will it be possible for man to become human with man in time to solve the problems which face him? Will his intelligence lead to adaptive survival or destruction?

Can intelligence solve such problems as the rapidly increasing populations of the world with its many and diversified facets, the depletion of farm lands, the decreasing supplies of natural resources, the destruction of the wild populations of pollinating insects and the natural enemies of insects, the failure and diminution of more and more of our promising insecticides, the increasing ravages of crops, and the increasing spread by modern travel of insect borne diseases of man?

Can intelligence cope with and solve the international political situation, especially when this is linked with increasing stockpiles of bigger and more deadly bombs and missiles for human destruction?

If it cannot, the insect may eventually win and eliminate man from its world, and what Dr. W. J. Holland said, might come to pass, ". . . the last living thing on the globe will be some active insect sitting on a dead lichen which will represent the last of the life of the plants."